DUKC Optimiser: Maximising Cargo Throughput at a Bulk Export Port

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Abstract

This demo presents DUKC® Optimiser – a system for maximising cargo throughput at a bulk export port by scheduling sailing times and drafts for a set of ships. An earlier prototype of the system underwent user testing in 2010 (Kelareva 2011), and a number of improvements resulting from user feedback have been incorporated in this updated version.

DUKC® Optimiser is the first system for automatically scheduling ship sailing times and drafts at a bulk export port which takes into account time-varying draft restrictions that take into account live environmental conditions. The system uses the Dynamic Under-Keel Clearance (DUKC®) software developed by OMC International to calculate draft restrictions. These restrictions are then converted to a contraint programming model, and solved using the G12 finite domain solver, developed by NICTA.

The software is able to find optimal schedules for realistic problem sizes, and is able to produce schedules which allow ships to carry more cargo than would be permitted by traditional constant-draft or manual scheduling approaches.

1 Introduction

At a bulk export port, the port authority aims to maximise cargo throughput at the port while maintaining safety. One key aspect of safety is restrictions on ship draft. Draft is the distance between the waterline and the bottom of the ship's keel, which increases as more cargo is loaded. Most ports have restrictions on maximum draft for ships entering and leaving the port, as loading a ship beyond the safe draft limit may result in the ship running aground.

At most ports, draft restrictions vary over time, and depend on the estimated under-keel clearance (UKC – amount of water under the keel) which varies with tide, wave, current and wind conditions. The Dynamic Under-Keel Clearance (DUKC®) software developed by OMC International has been very effective at increasing both maximum draft and safety by improving accuracy of UKC modelling at ports, thus reducing the conservatism required to maintain safety (OMC International 2009). Many ports worldwide now use DUKC® software to calculate draft restrictions, as this enables more cargo to be loaded onto ships without compromising safety.

Scheduling ship sailing times and drafts at bulk export ports is currently done manually or using simple tools such as Microsoft Excel. When ports use static under-keel clearance constraints that depend only on long-term tide forecasts, these constraints are same for all ships and don't need to be adjusted as enviro data is updated. However, with DUKC® software, the draft constraints vary between ships, and may be updated as enviro predictions change. DUKC® predicts under-keel clearance more accurately, thus enabling more cargo to be loaded onto ships, but it makes scheduling more complex and may require changes to the schedule if conditions change.

DUKC® Optimiser is a new tool that aims to simplify scheduling of ship sailing times and drafts for bulk export ports that use DUKC® software to calculate draft restrictions. DUKC® Optimiser also aims to find optimal schedules that allow ships to carry more cargo than schedules produced by human schedulers.

2 DUKC® Optimiser Background

A command-line prototype of DUKC® Optimiser was developed and tested by port schedulers in late 2010, and demonstrated at ICAPS 2011 (Kelareva 2011). An updated model containing improvements based on user feedback was incorporated in a commercial system in 2012 (Kelareva et al. 2012a).

The major improvement to the model in this version was the introduction of constraints on the availability of tugs – small boats that are used to assist ships to enter or leave port. User testing in late 2010 found that tug availability could constrain the schedule, so schedules produced by the model without tug constraints could be infeasible in practice. Tug constraints therefore needed to be incorporated before the system could be used in practice.

Another major improvement was improving the speed of the model, as described in (Kelareva et al. 2012a) and (Kelareva et al. 2012b).

The initial prototype was command-line based, which was sufficient to gather initial user feedback on schedule quality, but would have been inconvenient for operational use. The scheduling system was therefore incorporated into a commercial web-based dynamic under-keel clearance management system - DUKC® Series 5, developed by OMC International.

Vessel Beam, LBP	Sailing Draft	Sailing Slot Open Time	Sailing Slot Close Time
(A) AMIRA (32.26m, 217m)	16.00m	25May2012 0910	25May2012 0925
(B) BEGONIA (45m, 280.8m)	18.00m	25May2012 1235	25May2012 1250
(C) CAMELLIA (50m, 300m)	**18.75m**	25May2012 1145	25May2012 1200
(D) DIONE (45m, 283m)	18.00m	25May2012 1020	25May2012 1035
(E) EURYDICE D (42.5m, 267.6m)	18.00m	25May2012 1050	25May2012 1105
(F) FIRST JUPITER (45m, 277m)	**17.45m**	25May2012 1255	25May2012 1310

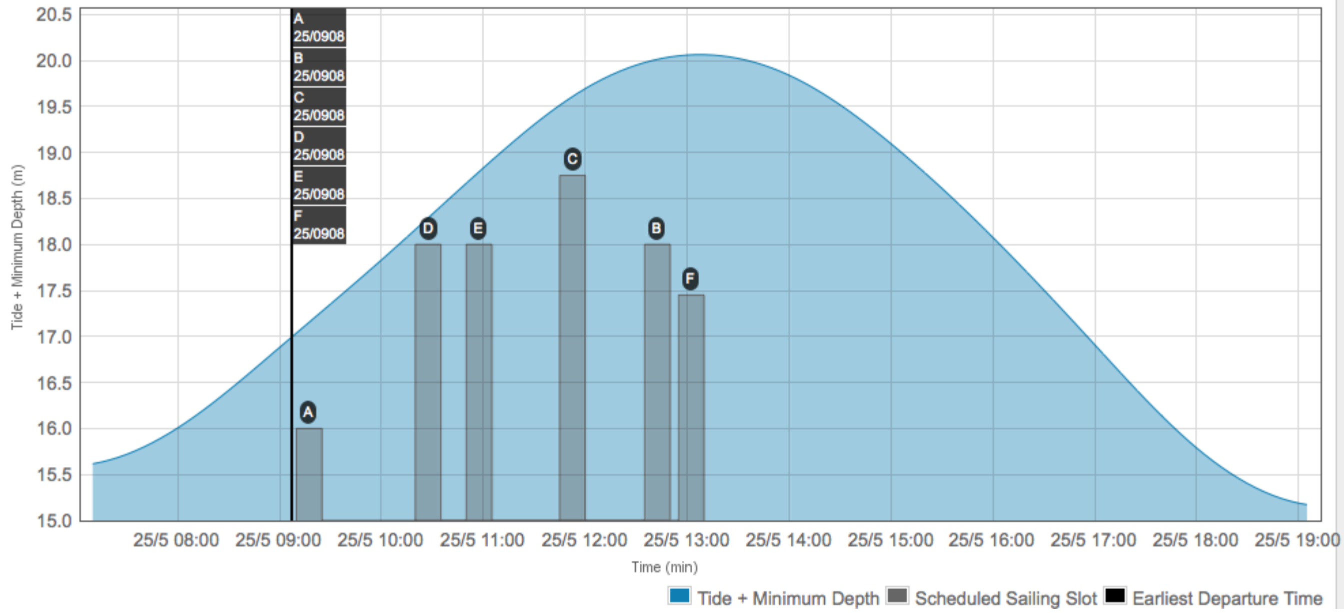

Figure 1: DUKC® Optimiser Result

3 Implementation

3.1 User Interface

To run a DUKC® Optimiser calculation, the scheduler must enter parameters such as length and beam for each ship that are used to calculate under-keel clearance. Other inputs required to calculate a schedule include the earliest sailing time for each ship, the number of tugs required for each ship, the range of drafts to calculate, and a priority number that is used to ensure fairness to different companies using the port.

Figure 1 shows an output schedule for a set of six ships sailing on one tide. In the graph on the bottom half of the screen, each bar represents a ship, with the height of the bar corresponding to the draft that the ship is scheduled to sail with, and the location of the bar along the x-axis indicating the time at which the ship is scheduled to sail. Each ship is scheduled with a time slot of 15 minutes, rather than a fixed time point, as it is impractical to expect a large bulk carrier to sail precisely at a given minute.

The blue curve indicates the minimum water depth along the channel plus the height of the astronomical tide prediction at that point in time. This does not take into account wave response, squat, heel, safety factor, or variation from the astronomical tide prediction, all of which can decrease the amount of water available to the ship. This results in the height of the blue curve being significantly above the height of the bars indicating ship draft.

3.2 Other Features

The web-based DUKC® Series 5 system includes a number of additional features to assist port schedulers, pilots and harbourmasters in making ship scheduling and sailing decisions. Port administrators may limit user permissions to only access schedules for ships belonging to their organisation, or to only access features that are required for their job. The system can also display live environmental data, such as measurements from wave buoys and tide gauges. The system also includes the DUKC® calculations used to provide under-keel clearance advice to pilots and ship captains immediately prior to sailing, and an in-transit monitoring tool that tracks the locations of ships at the port.

3.3 System Architecture

When the scheduler selects a set of ships to be scheduled in the web-based GUI, a query is sent to the DUKC® Optimiser server. Upon receiving a schedule query, DUKC® Optimiser converts it into a set of queries to OMC's DUKC® software. The DUKC® software uses real-time environmental forecasts and measurements to analyse each ship's motion, and thus to calculate the ship's under-keel clearance – the amount of water under the ship at each point in the transit. This produces sailing windows for a range of drafts for each ship.

DUKC® Optimiser then converts the user inputs and the results of the DUKC® calculations into a Constraint Programming (CP) model, implemented in the MiniZinc opti-

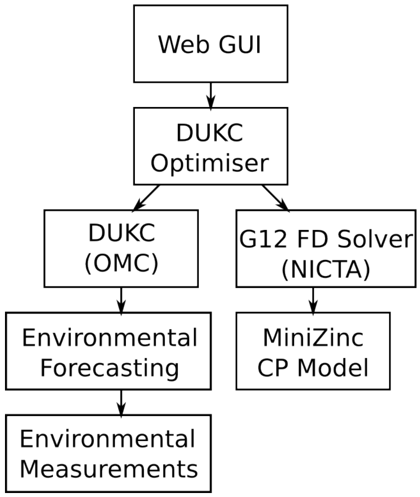

Figure 2: DUKC® Optimiser System Architecture

misation language (Nethercote et al. 2007). This model is then solved using the G12 finite domain solver (Stuckey et al. 2005). The GUI then displays the resulting schedule.

3.4 Constraint Programming Model

The constraint programming model, including speed improvements from the older command-line version, is discussed in detail in (Kelareva et al. 2012a). The model is only described briefly here.

Basic Model The decision variables in the Constraint Programming model used to create schedules are the sailing times for each ship. The maximum draft for each ship is a function of time, specified at 5-minute intervals, as the maximum draft allowed by the DUKC® may change rapidly.

The main constraints of the original model without tugs are:

- Constraints on the earliest time when each ship may sail.
- Constraints on the availability of berths for incoming ships.
- Constraints enforcing minimum separation time between successive ships.

Tug Constraints Tug constraints proved to be very difficult to implement efficiently, as tug job durations depend on both the ship the tug is working on, and the ship it will work on next. After several unsuccessful attempts, we found an implementation that was able to solve realistic problem sizes within 5 minutes by splitting the sequence of ships into four types of scenarios, as shown in Figure 3, and calculating tug constraints separately for each scenario.

Objective Function The objective function may vary between ports – some ports may only maximise throughput; other ports may prioritise fairness to competing clients above maximising total throughput for the port. A port objective function may also need to take into account shipping contracts used by shippers at the port, as these may affect the cost and benefit to shippers of sailing with more or less draft.

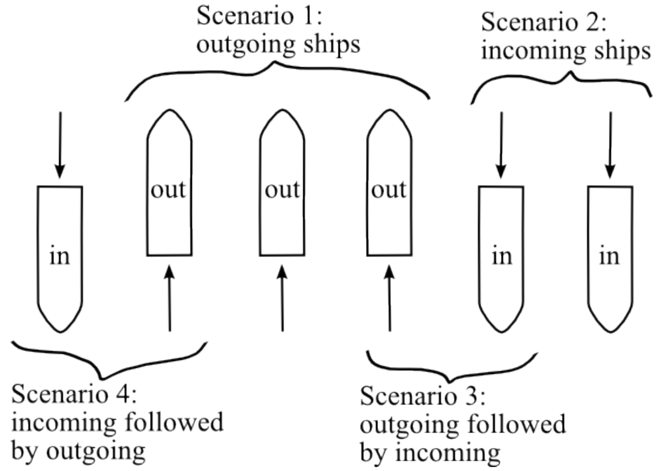

Figure 3: Scenarios for Tug Constraints

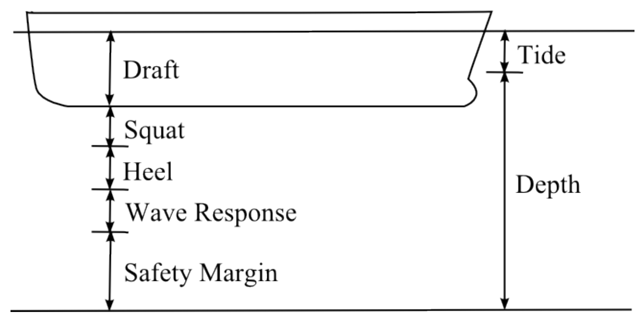

Figure 4: Dynamic Under-Keel Clearance Components

3.5 Dynamic Under-Keel Clearance

Figure 4 illustrates components of ship motion taken into account by the DUKC® software. These include:

- **Draft:** the distance from the waterline to the bottom of the ship's keel.
- **Squat:** a phenomenon which causes a ship travelling fast through shallow water to sink deeper into the water than a ship travelling slowly.
- **Heel:** the effect of a ship leaning towards one side, caused by the centripetal force of turning, or the force of wind on the side of the ship.
- **Wave Response:** motion resulting from the action of waves on the ship. Only the vertical component of this motion affects under-keel clearance.

Under-keel clearance is computed as follows:
UKC = Tide + Depth - Draft - Squat - Heel - Wave Response

If the under-keel clearance is below the required safety limit, then the DUKC® software will advise the operator not to sail. However, the final decision always rests with the ship's pilot or captain.

For a more detailed analysis of Dynamic Under-Keel Clearance methodology, see (O'Brien 2002).

4 Benefits

Existing ship scheduling approaches either leave draft constraints entirely up to human schedulers (Fagerholt 2004), or use simple constant draft constraints that do not vary with time (Christiansen et al. 2011) (Song and Furman 2010). Scheduling of ship sailing times at a port is usually done manually by human schedulers following simple heuristic rules such as scheduling the ship with the largest maximum draft first, and scheduling each ship at the earliest time it can sail (Kelareva et al. 2012a).

Both of these approaches can lead to suboptimal schedules where ships carry less cargo than the maximum. An example presented by (Kelareva et al. 2012a) shows that even for a simple schedule with three ships, fixed-draft and manual scheduling approaches can fail to find the optimal schedule, resulting in 10cm less total draft. An average Capesize iron ore carrier can transport 130 tonnes of iron ore per centimetre of draft (Port Hedland Port Authority 2011), so this results in around US$221,000 less iron ore being transported on the three ships, at the January – October 2011 average iron ore price of around US$170/tonne (Index Mundi 2011).

This small example clearly shows the financial benefit of using accurate time-varying draft constraints and optimal schedules. These are simple examples with only three ships, all berths at the same location along the transit, and no tug constraints taken into account. Real schedules would be even more complex and difficult to optimise manually.

5 Conclusions

We have presented DUKC® Optimiser – a web-based system for maximising throughput at a bulk export port by scheduling ship sailing times and drafts. It uses the Dynamic Under-Keel Clearance (DUKC®) software developed by OMC International to calculate constraints on allowable drafts for each ship at each point in time, taking into account the effects of tide, waves and current on ship motion.

DUKC® Optimiser contains a constraint programming (CP) model implemented in the MiniZinc optimisation programming language, which is solved using the G12 finite domain solver developed by NICTA. Major constraints include sequence-dependent separation times between ships and constraints on the availability of tugs.

The system has undergone user testing in 2010 (Kelareva 2011), and user feedback has been incorporated into an updated version (Kelareva et al. 2012a).

A comparison of optimal schedules produced by DUKC® Optimiser against constant-draft ship scheduling approaches and schedules produced by simple heuristics used in practice at ports has demonstrated that DUKC® Optimiser is able to find optimal schedules which allow ships to load more cargo than either fixed-draft or naive manual scheduling approaches (Kelareva et al. 2012a). This shows that DUKC® Optimiser may provide a large benefit to industry, as every centimetre of extra draft allows more cargo to be carried on the same set of ships, thus reducing transportation costs.

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